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Review

Radial artery as graft for coronary artery bypass surgery: Advantages and disadvantages for its usage focused on structural and biological characteristics

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ABSTRACT

Radial artery (RA) is the most popular arterial graft after the left internal thoracic artery in both low- and high-risk patients undergoing coronary artery bypass grafting. Various arterial grafts such as the right internal thoracic artery, the right gastroepiploic artery, and the inferior epigastric artery have also gained ground over the past 30 years because of the intimal hyperplasia and atherosclerosis of the saphenous vein leading to late graft occlusion. In this review article we would like to present the utility of the RA as a graft, focused mainly on its structural and biological characteristics.

Contents

Introduction

The internal thoracic artery (ITA) graft, having a patency rate of approximately 90% as a bypass conduit to the left anterior descending artery (LAD) at 10 years after coronary artery by-pass grafting (CABG) [1–3], is considered superior [4] to the saphenous vein (SV), having a patency rate of 50–60% [1–3]. Therefore, left internal mammary artery (LIMA) to LAD graft, reducing late cardiac events after CABG and improving survival rates [5–7], has become the gold standard of care [8]. Various arterial grafts – the right internal thoracic artery (RITA) [9,10], the right gastroepiploic artery (GEA) [11,12], the radial artery (RA) [13,14], and the inferior epigastric artery (IEA) [15,16], have also gained ground over the past 30 years because of the intimal hyperplasia and atherosclerosis of the SV leading to late graft occlusion. In general, arterial grafts demonstrate superiority to the SV long-term patency [17,18]. Carpentier et al. [19] were the first to introduce the RA graft for CABG in 1973. Poor short-term results (35–50% graft occlusion rate) due to spasm [20] and intimal hyperplasia [21], resulted in the abandonment of its use as a graft. Nevertheless, in 1992, Acar et al. [14] discovered incidentally that previous RA grafts were free from

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progressive graft disease and they reintroduced the RA as a conduit for CABG thanks to its good length, suitable inner diameter, ease of handling, minimal donor site discomfort, and remarkable short-, mid-, and long-term patency [22–24]. Although it is prone to early spasm because of its muscular structure, specific surgical techniques [25,26], and pharmacologic prophylaxis in preoperative and postoperative periods [25,27] can prevent it. In our days, the RA is the most popular arterial graft after the ITA [28] in both low- and high-risk patients [29].

RA harvesting technique

The nondominant hand is usually the donor site of the RA [30]. RA harvest can be open or endoscopic, with or without the aid of the ultrasonic scalpel, pedicled or skeletonized [31]. RA grafts harvested by ultrasonic scalpel present importantly greater blood flow than traditionally harvested RA grafts [32]. Conventional RA harvest is performed in the way which Reyes et al. described in 1995 [33]. A full-length forearm incision along the course of the RA is made extending from a point just before the palpable biceps tendon to a point between the tendon of the flexor carpiradialis muscle and the radial styloid [34]. Opening of the subcutaneous fat and deep fascia over the brachioradial muscle and radial flexor muscle of the wrist follows in order to expose the radial artery. Clips are located at all side branches which are then divided by electrocautery [35]. Before wound closure, careful hemostasis must be realized to minimize the possibility of postoperative compartmental syndrome in the forearm [34]. Harvesting the RA with the accompanying veins and fat, minimal handling of the graft, limited use of electrocautery, and avoiding probing or hydrostatic dilation of the conduit are some important clues [33]. Psacioglu et al. [36] introduced in 1998 a modified RA harvesting technique. Using an ultrasonically activated scalpel and without clipping the vessel side branches, they managed to improve the harvesting time, the frequency of spasm, and the trauma [36]. The harmonic scalpel (HS), being used even through endoscopic devices, can cut and coagulate causing minimal thermal injury of the graft [25,32,37–41]. Searches with the scanning electron microscope [42] and Lamm et al. [43] reported that when HS is used, the trauma to the endothelium of the conduit is reversible in comparison to conventional electrocautery. This technique with the HS can constitute a remarkable alternative to endoscopic RA harvesting as it is shorter, no clips are used, it costs less, and complete bleeding control is possible [44]. Connolly et al. [45] have described an endoscopic RA technique. The patient is lying on the back, with the arm in abduction and the wrist in hyperextension. The skin is cut 3-cm longitudinally beginning 1 cm proximal to the radial styloid so as for the Ultra-Retractor to be introduced and then, the RA is harvested as a pedicle with its accompanying veins and fat, assisted by a video with a 30-scope using the harmonic shears. Endo-scissors are used to divide the artery. Better exposure is achieved using CO_2 insufflation [30]. On the other hand, the skeletonization technique pressuposes the removal of all surrounding tissue of the vessel, improving the graft length, diminishing the sternal wound infection rates for left (LITA) and bilateral (BITA) ITA grafts [26] and demonstrating high long-term patency [25]. A better spontaneous blood flow through the more dilated skeletonized LITA in comparison with the pediculed LITA was confirmed by both Choi and Lee [46] and Wendler et al. [47]. Additionally, the skeletonization technique insures better response of the LITA conduits to the intraluminal vasodilators [46]. According to Miyagi et al. [48], Amano et al. [25] and Ali et al. [26], skeletonization of the RA is superior to the pedicled technique in terms of patency rates, ranging from 96.5% to 100% vs. 77.5% to 86.7%, respectively. However, there are also disadvantages, such as irreversible injury to the RA or spasms provoked by electrocautery, depending both on the surgical material and experience [27]. As well, the subfascial dissection (fasciotomy) of the nervous plexus prevents spasm because of less contact with the RA graft during anastomosis. The posterior subfascial area is dissected along the whole RA graft length for the purpose of sympathectomy improving the blood flow through the conduit. Moreover, less damage to the vessel which is kept dilated occurs [27]. In general, attention has to be paid to the reduction of the surgical trauma around the radial nerve, avoiding the direct use of knife, scissors, or cautery and indirect harm of nerve (retractor, heat from cautery), as well as at the harvest of the distal portion of the RA in order for the median nerve blood supply not to be limited because of clips of branch vessels [49].

Preoperative exclusion criteria for RA harvesting

The Allen test is the most widely used clinical test for preoperative evaluation of sufficient ulnar collateral circulation to the hand [31,50,51]. A modified Allen test, using a pulse oximeter placed on the thumb, contributes to assure an intact palmar arch observing the pulse and saturation [30,49]. The pulses of the RA and of the ulnar artery (UA) show their location. The examiner holds lightly the patient's wrist between the thumb and fingers placing simultaneously each thumb over the RA and UA. The patient, after having closed his or her hand as tightly as possible for a period of 1 min, relaxes it avoiding hyperextension, and the UA is then released. If the color to the hand and fingers and oxygen saturation return to normal within five seconds, the test is normal. Recovery after the passing of this time means an abnormal Allen test result [50,51]. Despite being a gold-standard screening method for forearm occlusive disease, the Allen test presents a high false-positive rate [52–55]. Therefore, it has been criticized [56,57] for being too unreliable and subjective. Although it excluded 5–10% of CABG patients from RA harvest [52–55] (15–23% in other studies [56–58]), the RA could be safely dissected from most of these patients [52–55]. Abu-Omar et al. [50] reported that 88% of patients with a positive Allen test had no forearm arterial occlusive disease according to Doppler ultrasonography, thus the RA could be harvested without any ischemic complications in the hand. A rare case of severe hand ischemia in a patient despite a negative Allen test result was also reported [13,59–62]. A well-developed collateral circulation [63], a superficial dorsal branch of the RA, or a median artery [64] can provoke such a misleading result. Hence, other supplementary assessment techniques, such as digital plethysmography, and Doppler ultrasonography, have been used [50].

Doppler ultrasonography of RA not only allows for the evaluation of the ulnar collateral circulation to the hand, but also for the preoperative estimation of poor RA quality because of a small diameter, vessel wall arteriosclerosis, or calcification [35]. Hence, all patients should have a Doppler study done [65]. Nevertheless, ultrasonography- or plethysmography-based screening tests have also a relatively high false-positive rate [66–72]. Ultrasonographic scanning of the full-length UA, as proposed by Abu-Omar et al. [50], appears to have a relatively low false-positive rate, thus augmenting the number of patients proper for RA harvest.

RA characteristics

The RA is an advantageous conduit. It has an adequate length to reach any coronary vessel [73] (more than 20 cm on average [31]), can be harvested with the IMA and SV at the same time, is easy to manipulate surgically [13,52,74] having a more superficial anatomical location [35], is less risky for sternal wound infection and mediastinitis compared to use of RITA or BITA [35,75], has higher patency rates compared to saphenous vein grafts [13,52,74], and has fewer infections than saphenous vein sites [76]. Proper diameter (2–3 mm without size mismatch to the coronary arteries [31]), robust structure, and relative resistance to kinking are some additional advantages of the RA [73]. However, the neurologic problems [49], which have been described as the most common complications following RA harvest [77,78], constitute a serious problem of the RA harvesting and the tendency for vasospasm is its most important negative characteristic [79]. According to histologic studies, its elastic laminae have one layer with multiple fenestrations. This is the reason why the RA presents a vulnerability to atherosclerosis [80]. Moreover, diabetes mellitus and renal dysfunction aggravate vascular wall morbidity [81,82]. According to Gaudino et al. [83] atherosclerotic changes in the RA had little influence on the mid-term graft patency rate, whereas Ikeda et al. [84] demonstrated postoperative accelerated intimal hyperplasia in RA grafts. However, although graft disease, meaning progressive atherosclerotic change, is a common situation as early as 5 years after surgery in SV grafts [85], no such situation is found in RA conduits [85,86]. He et al. noted that the RA produced less NO than the ITA [87]. Additionally, the media of the RA is approximately 1.7-fold thicker than the ITA media including many smooth muscle cells arranged in several layers [88,89], whereas the IMA is composed of more elastic components [90]. However, the greater contractility of the RA is also dependent on a receptor-mediated mechanism [91], as the RA and ITA have different subtypes of a receptor on smooth muscle cells [92,93]. Moreover, the intense reactivity of the RA to vasoactive mediators, such as endothelin I, angiotensin II, norepinephrine, serotonin, and thromboxane A, being released after endothelial damage caused by surgical trauma and platelet aggregation, can also explain its spastic character [14,94]. In addition, the flow competition phenomenon with mildly stenotic native coronary arteries is common in RA grafts [95–103]. Spasm but not vessel occlusion may be observed in a small percentage of cases. This phenomenon “string sign”, is presented in target vessels with stenosis less than 90% and in patients needing alpha adrenergic agonists [22,25,52,84,94].

RAs present similar long-term clinical results and angiographic patency rates to these obtained with IMAs [104]. Several studies [52,105–109] show mid- and long-term patency rates from 83% to 96.8% after RA harvesting. Nevertheless, the severity of the target vessel stenosis significantly influences the RA patency rate [110]. According to Royse et al., RA grafting to a vessel being less than 70% stenosed led to a significantly decreased patency rate, whereas more than 40% stenosis of the target vessel had no impact on the patency rate of the ITA graft [96]. However, the target vessel location minimally influences the RA patency rate, while there is a remarkable influence of the target vessel location on the RITA patency rate (patency rate of RITA to LAD, 91.9%; left circumflex artery – LCX, 90.1%; right coronary artery – RCA, 83.1%) [28].

RA grafts demonstrate similar patency either as composite grafts with the LITA as Y or T grafts or as an aortocoronary bypass [98–100]. However, Gaudino et al. proved that flow competition was more frequent in the composite RA conduits [101]. Their long-term patency was also poor by angiographic analysis, but it was better than the SV when there was good forward flow [97,102,103]. Other disadvantages of composite compared with aortocoronary grafts are the technical difficulty and the fact that the supply of many coronary territories is dependent on the flow of a single vessel [95].

Older and diabetic patients are prone to have distal calcification in the RA. In reoperations, a special problem is the cannulation of the RA at the first operation for arterial monitoring, resulting in distal RA fibrosis. If the RA is not absolutely normal, the distal fibrotic portion can be left in situ and the proximal RA can be used [73]. But what are the advantages of RA as a graft for the elderly? Firstly, despite atherosclerotic changes of the RA in the elderly with coronary heart disease [111], the RA has still good quality and function [35]. Similar functional results in elderly and young patients are observed [112]. Afterward, it is easy to manipulate and harvest this graft with minimal harvest site complications. Finally, the long-term patency of RA for the elderly is considerable too [35]. According to a some studies [113,114], improved early clinical and cosmetic results, decreased hospital expenditure, decreased morbidity, and improved mid-term outcome are observed using RA as a graft in the elderly. Moreover, Chen et al. [35] proved that the patency rate was 95.8% for RA, 77.4% for SV graft, and 97.2% for LIMA. In conclusion, the safety and effectiveness of the RA as a graft in elderly patients, makes it absolutely appropriate for CABG [35].

Graft spasm without any clinical signs may occur shortly after the operation, because of maximal RA reactivity within days of the operation [52]. Reversible spasm is more frequent than is believed and unstable hemodynamics can declare spasm only in grafts supplying with blood critical coronary territories [115]. Moreover, the mechanism of severe spasm in the RA appears to be more difficult to reverse compared with the LITA [116]. Spasm of the RA is reported to happen in 4–10% of patients [114]. In order to prevent it, no-touch technique or techniques avoiding endothelial damage should be used [104]. Hence, the pedicled technique is simultaneously easy to learn and appropriate to minimize irritation to the conduit [35]. In addition, Maruo et al. [117] demonstrated in vitro arterial dilation in response to ultrasonic stimulation, because of an endothelium-dependent release of nitric oxide and prostacyclin. The gold standard to prevent RA spasm is systemic administration of diltiazem, in combination with topical spray of papaverine [118] and the intraluminal injection of warm arterial blood including papaverine [24,35,118,119]. Other topical RA antispasmodic factors in clinical use are calcium channel blockers, verapamil, and nitroglycerin (VG solution), phenoxybenzamine, and a phosphodiesterase inhibitor [90,120–124]. Avoidance of cold saline or ice slush in the pericardium is also significant to prevent spasm [125].

These are the basic characteristics of each anti-spastic agent. Oral diltiazem should last for more than 6 months [35]. The antispasmodic action of papaverine was found to last for approximately 1 h, whereas VG solution was effective for 5 h [126] better preserving endothelial function than papaverine [120]. According to an in vivo study phenoxybenzamine caused vasorelaxation for up to 16 h, but it had little action on vasoconstriction mediated by noncatecholamine vasoactive mediators [127]. Clinically, phenoxybenzamine was superior to VG solution in decreasing myocardial injury and perioperative adverse cardiac events [128]. Finally, milrinone, a long-acting phosphodiesterase inhibitor, had good clinical results when infused intraluminally to prevent RA spasm [124].

In a study by Yoshizaki et al. [115] including 215 patients, topical use of VG solution led to better patency of RA grafts than papaverine, which was confirmed by angiography more than a year after the operation. Moreover, although papaverine causes vasorelaxation through multiple mechanisms: phosphodiesterase inhibition, decreased calcium influx, and inhibition of the release of intracellularly stored calcium [129], it is very acid, resulting in damaged endothelium [130–132]. Harm of the endothelium induces clot formation and abnormal proliferation of endothelial cells, causing graft occlusion. These points also show the superiority of VG solution to papaverine [131,132]. As far as phosphodiesterase III inhibitors are concerned, they are beneficial to systemic hemodynamics, increasing cardiac output and reducing systemic vascular resistance [133]. On the other hand, phenoxybenzamine binds irreversibly to α-adrenoreceptor, so treatment during surgery can last throughout the postoperative period (48 h) [134]. However, some supplementary treatments are necessary to prevent spasm, because it is effective only in α-adrenergic-mediated vasoconstriction [135].

Complications after RA harvesting

Conventional RA harvesting is accompanied by significant morbidity including bleeding, hematomas, wound infection, motor, and sensory nerve complications. The rate of these complications wavers from 0.5% to 67% [13,52,74,77,105,136–138]. Nevertheless, major complications such as hand ischemia, wound infection, and hematomas are rare with this surgical approach (0.2% and 1.5%) [13,52,74,77,105,136–138]. Significant problems after RA harvesting concern scars [30] and sensory nerve injuries, causing sensory abnormality and numbness in 3–15% of patients [139,140]. Motor impairments are usually early findings of little clinical importance [136,141]. Finally, although severe hand ischemia after RA harvest is rare [13,59–61], patients suffering from forearm arterial occlusive disease are prone to this complication [110]. After RA harvesting, the UA dilation compensates for the loss of the RA [110]. According to a plethysmographic study [142], after RA harvesting, its diameter increased by 15.7% and its flow velocity increased by 17.4%. However, Doppler ultrasonographic studies, showed a reduction by 20% in the total forearm blood flow [143,144]. A questionnaire-based survey, reported hand weakness, reduced with time, in fewer than 6% of patients [137,140] and limitation in hand activity again in fewer than 6% of patients [137,145,146]. Hence, in general, the postoperative function of the affected hand is acceptable with no serious limitations in daily hand activity [110].

Patients complain about various hand problems after RA harvesting for CABG [77,78,136,147–151]. Either radial nerve injury or median nerve injury can cause these neurologic complications. The radial nerve has both motor and sensory branches for the hand, such as the proximal interosseus nerve controlling the motion of the thumb and finger extensors and 4–5 sensory branches for the dorsum of the hand and for a fraction of the lateral thenar [49]. Dorsal sensory abnormality means injury of the superficial radial nerve, as it is close to the RA [77,136,137]. Radial nerve damage can also provoke numbness [29,136,137] whereas median nerve damage can cause palmar sensory abnormality and thumb weakness [77], which is due to weakness of the flexor pollicis longus, a muscle innervated by a branch of the median nerve, the anterior interosseus nerve [49]. The RA is also able to supply these structures with blood [77]. Direct injury during RA harvesting or edema around the superficial nerve or lateral cutaneous nerve of the forearm are responsible for the radial nerve damage [77,138]. As far as the median nerve is concerned, there is no direct injury due to its relevant distance from the RA [77], but a local carpal tunnel hematoma or edema may be responsible [49]. Ischemia constitutes another reason for the damage of both of these nerves [49]. Royse et al. [136] in a study of 2167 harvested RAs observed that the territory of the lateral antebrachial cutaneous nerve (LABCN) had been affected in 15.5% of patients, having sensory symptoms and the territory of the superficial radial nerve (SRN) in 11.3%. Only 5% mentioned difficulty with daily activity. According to a study of Meharwal et al. [137] in 3977 patients, the incidence of sensory symptoms was 28%, decreasing with time, whereas 12% mentioned limited hand activity. Moreover, Dogan et al. [34] observed that median sternotomy, left chest retraction, and arm abduction harm the motor function of median and ulnar nerves. Chest retraction and arm abduction mostly influence the ulnar nerve and mechanical trauma is more harmful for radial and median nerves. Consequently, a less invasive endoscopic technique has been used, so as to minimize the morbidity and cosmetic disadvantages of RA harvesting [40,45,152]. Although elimination of injury to the LABCN is observed, the SRN continues to be affected. However, cosmetic results are much better than in conventional harvest [30].

Comparison

RA conduits appear to be superior to SV grafts in terms of early and late mortality and morbidity [153,154]. RA is associated with better survival and freedom from cardiac events [155]. According to several angiographic observational studies [14,52,86,104–108,149,154,156–159] the RA either as an aorto-coronary bypass or as a composite graft reached excellent short- (96–100%), mid- (94–97%), and long-term graft patency (84–96%), having exceeded SV graft patency. However, some studies demonstrated similar long-term graft patency [75,98,101,159] and only the Cleveland Clinic found that SV graft patency was superior to this of the RA [160]. According to Possati et al. [86] RA grafts had worse long-term (105 ± 9 months) graft patency (88%) than LITA (96%), but better than SV (53%). The Radial Artery vs. Saphenous Vein Graft Patency (RSVP) trial [22] proved that the graft patency of the RA to the circumflex coronary artery at 5 years (98.3%) was better ($p = 0.04$) than that of the SV (86.4%) and graft narrowing happened in 10% and 23% of patent RA and SV grafts, respectively ($p = 0.01$). Nevertheless, the SV graft is still preferable as a graft to the right coronary territory because composite RA grafts to the right coronary branches are prone to flow competition [13,95–97,100,161] and the RITA to the right coronary artery presents lower early graft patency [162,163]. Moreover, sternal infection happens less frequently when RA conduits are used rather than when VGs are used, probably because of the cleaner donor site compared with legs and thighs. Avoidance of leg incisions in order for the patient to be faster mobilized [73], limiting the risk of acute pulmonary embolism caused by deep vein thrombosis [164], is also significant, as well as the lower rate of donor site complications accompanying RA harvesting [73]. Dermatitis, cellulitis, greater saphenous neuropathy, chronic non-healing wounds, and lymphoceles are the most common leg-wound complications after SVG harvesting being associated with substantial morbidity, longer hospital stays, higher hospital costs, later mobilization, and additional surgical procedures [53]. Tatoulis et al. [165] evaluated 2417 patients after RA harvesting and reported a 0.08% incidence of fingertip ischemia, a 0.4% incidence of forearm hematoma, and no major forearm infections, whereas leg-wound complications after SVG harvesting range from 1% to 24% [166–168]. In another study [164], infection at the harvest site was observed in 6.4% of the patients who received an SV graft, but none receiving arterial conduits. Moreover, diabetics and elderly patients undergoing RA or SV CABG demonstrate similar results. Erdil et al. [164] reported that, among patients of 65 years and older, there were similar perioperative morbidity and mortality rates, as well as similar early postoperative outcomes after CABG either using mostly RAs or a mixture of arterial grafts and SVs. All the LIMAs were patent, as were 90.9% of the RAs, and 86.9% of the SVs. However, higher numbers of graft-harvest-site infections and longer hospital stays also accompanied SV harvesting [164]. In another study [155], RA grafts were superior to SV grafts in terms of mean flow of circumflex coronary artery grafts and graft flow reserve of right coronary grafts in diabetics and in terms of mean flow of circumflex coronary artery grafts in the elderly. On the other hand, RITA and RA demonstrate equivalent clinical and angiographic results during the first 5–8 years, when they are grafted to a non-LAD lesion [75,110,169], although RA is less associated with perioperative bleeding and sternal wound infection [75]. Buxton et al. [170], Lemma et al. [75], and Calafiore et al. [169], all showed no differences in survival rates and cardiac event-free survival rates between patients with an RA graft and those with an RITA graft. Moreover, although BITA use appears to be superior to only LITA use [171–173], patients taking insulin or steroids, who are obese or have chronic obstructive lung disease are prone to sternal wound infection after BITA harvesting [174,175]. In addition, the RITA to LAD graft crosses the midline of the chest obstructing potential reoperations [31].

Contraindications for RA harvesting

Forearm ischemia, as well as severe atherosclerosis with calcification, dissection from prior cannulation [31], significant RA stenosis as revealed by Doppler ultrasonography, and a history of vasculitis or Raynaud's disease [164] constitute contraindications for RA harvest. Moreover, it has been reported that patients having peripheral vascular disease, diabetes mellitus (also reported as a predictor for RA spasms [176]) or elevated levels of creatinine are vulnerable to neurologic complications after RA harvesting [77]. Siminelakis et al. [49] also proved a connection between the predictor variables, such as Euroscore, congestive heart failure, diabetes mellitus, hypertension, perioperative use of intraaortic balloon pump and low or moderate ejection fraction, and neurologic abnormalities after RA harvesting. Apart from neurologic problems, congestive heart failure, hypertension [49], and low Euroscore also constitute a factor predicting hand complications [177]. Additionally, RA grafting seems to be inappropriate for <75% proximal coronary occlusion, particularly in the right coronary branches [31,74]. A study reported that right coronary territory patency was 82% vs. 94% for other territories ($p = 0.022$) after RA harvesting [96]. However, diabetes is not a limitation to RA-grafting [155,178], which can also be used to reduce harvest-site infections in alcohol-drinking patients [164]. Moreover, thrombotic occlusion, caused by preoperative cardiac catheterization before CABG, is not a contraindication to the use of RA after thrombectomy [31].

Conclusion

RA appears to be a good graft for CABG surgery [179]. Its harvesting is easy with minimal local neurological and vascular complications. Its length is adequate for every site and its patency appears to be superior to SV. The tendency for vasospasm is its most important negative characteristic.

References

[1] Grondin CN, Campou L, Lesperance J, Enjalbert M, Bourassa M. Comparison of later changes in internal mammary and saphenous vein grafts in two consecutive series of patients 10 years after operation. Circulation 1984;70(Suppl. 1):208–21.
[2] Bourassa MG, Fischer LD, Campeau L, Gillespie MJ, McConney M, Lespurance J. Long-term fate of bypass graft: the Coronary Artery Surgery Study (CASS) and Montreal Heart Institute experience. Circulation 1985;6(Suppl. V):V-71–8.
[3] Ura M, Sakata R, Nakayama Y, Arai Y, Saito T. Long-term results bilateral internal thoracic artery grafting. Ann Thorac Surg 2000;70:1991–6.
[4] Loop FD, Lytle BW, Cosgrove DM, Stewart RW, Goormastic M, Williams GW, Golding LA, Gill CC, Taylor PC, Sheldon WC. Influence of the internal-mammary-artery graft on 10 year survival and other cardiac events. N Engl J Med 1986;314:1–6.
[5] Naik MJ, Abu-Omar Y, Alvi A, Wright N, Henderson A, Channon K, Forfar JC, Taggart DP. Total arterial revascularisation as a primary strategy for coronary artery bypass grafting. Postgrad Med J 2003;79(927):43–8.
[6] Cameron A, Davis KB, Green G, Schaff HV. Coronary bypass surgery with internal-thoracic-artery grafts—effects on survival over a 15-year period. N Engl J Med 1996;334(4):216–9.
[7] Kurlansky PA, Williams DB, Traad EA, Carrillo RG, Schor JS, Zucker M, Singer S, Ebra G. Arterial grafting results in reduced operative mortality and enhanced long-term quality of life in octogenarians. Ann Thorac Surg 2003;76(2):418–27.
[8] Okies JE, Page US, Bigelow JC, Krause AH, Salomon NW. The left internal mammary artery: the graft of choice. Circulation 1984;70(Suppl. I):I-213–21.
[9] Ioannidis JP, Galanos O, Katritsis D, Connery CP, Drossos GE, Swistel DG, Anagnostopoulos CE. Early mortality and morbidity of bilateral versus single internal thoracic artery revascularization: propensity and risk modeling. J Am Coll Cardiol 2001;37:521–8.
[10] Tector AJ, Mc Donald ML, Kress DC, Downey FX, Schmahl TM. Purely internal thoracic artery grafts: outcomes. Ann Thorac Surg 2001;72:450–5.
[11] Suma H, Fukumoto H, Takeuchi A. Coronary artery bypass grafting by utilizing in situ right gastroepiploic artery: basic study and clinical application. Ann Thorac Surg 1987;44:394–7.
[12] Mills NL, Everson CT. Right gastroepiploic artery: a third arterial conduit for coronary bypass. Ann Thorac Surg 1989;47:706–11.
[13] Tatoulis J, Royse AG, Buxton BF, Fuller JA, Skillington PD, Goldblatt JC, Brown RP, Rowland MA. The radial artery in coronary surgery: a 5-year experience-clinical and angiographic results. Ann Thorac Surg 2002;73:143–8.
[14] Acar C, Jebara VA, Portoghese M, Beyssen B, Pagny JY, Grare P, Chachques JC, Fabiani JN, Deloche A, Guermonprez JL. Revival of the radial artery for coronary bypass grafting. Ann Thorac Surg 1992;54:652–60.
[15] Vincent JG, van Son JAM, Skotnicki SH. Inferior epigastric artery a conduit in myocardial revascularization: the alternative free arterial graft. Ann Thorac Surg 1990;49:323–5.
[16] Perrault LP, Carrier M, Hebert Y, Cartier R, Leclerc Y, Pelletier LC. Early experience with the inferior epigastric artery in coronary artery bypass grafting: a word of caution. J Thorac Cardiovasc Surg 1993;106:928–30.
[17] Reardon M, Conklin L, Reardon P, Baldwin J. Coronary artery bypass conduits: review of current status. J Cardiovasc Surg (Torino) 1997;38:201–9.
[18] FitzGibbon GM, Cafka HP, Leach AJ, Keon WJ, Hooper D, Burton JR. Coronary bypass graft fate and patient outcome: angiographic follow-up of 5065 grafts related to survival and re-operation in 1388 patients over 25 years. J Am Coll Cardiol 1996;28:616–26.
[19] Carpentier A, Guermonprez JL, Deloche A, Frechette C, DuBost C. The aorta-to-coronary radial artery bypass graft: a technique avoiding pathological changes in grafts. Ann Thorac Surg 1973;16:111–21.
[20] Carpentier A. Discussion of Geha AS, Krone RJ, Mc-Cormick JR: selection of coronary bypass: anatomic, physiologic, and angiographic considerations of vein and mammary artery grafts. J Thorac Cardiovasc Surg 1975;70:414–31.
[21] Curtis JJ, Stoney WS, Alford Jr WC, Burrus GR, Thomas Jr CS. Intimal hyperplasia: a cause of radial artery aortocoronary bypass graft failure. Ann Thorac Surg 1975;20:628–35.
[22] Collins P, Webb CM, Chong CF, Moat NE. Radial artery versus saphenous vein patency randomized trial: five-year angiographic follow-up. Circulation 2008;117:2859–64.
[23] Hayward PA, Hare DL, Gordon I, Matalanis G, Buxton BF. Which arterial conduit? Radial artery versus free right internal thoracic artery: six-year clinical results of a randomized controlled trial. Ann Thorac Surg 2007;84:493–7.
[24] Chen XJ, Zhang Y, Chen X, Feng WH, Li DL, Li HW. Role of radial artery in total arterial myocardial revascularization in coronary bypass surgery. Chin Med J (Engl) 2008;121:200–4.
[25] Amano A, Takahashi A, Hirose H. Skeletonized radial artery grafting: improved angiographic results. Ann Thorac Surg 2002;73:1880–7.
[26] Ali E, Saso S, Ahmed K, Athanasiou T. When harvested for coronary artery bypass graft surgery, does a skeletonized or pedicled radial artery improve conduit patency? Interact CardioVasc Thorac Surg 2010;10:289–92.
[27] Kucukarslan N, Kirilmaz A, Sungun M, Ozal E, Ulusoy RE, Sanisoglu Y, Tatar H. Harvesting of the radial artery: subfasciotomy or full skeletonization: a comparative study. J Card Surg 2008;23:341–5.
[28] Tatoulis J, Buxton BF, Fuller JA. Patencies of 2127 arterial to coronary conduits over 15 years. Ann Thorac Surg 2004;77:93–101.
[29] Reddy VS, Parikh SM, Drinkwater Jr DC, Lo A, Rauth TP, Moleski RM, Chang PA. Morbidity after procurement of radial arteries in diabetic patients and the elderly undergoing coronary revascularization. Ann Thorac Surg 2002;73(3):803–7 [discussion 807-808].
[30] Shapira OM, Eskenazi BR, Hunter CT, Anter E, Bao Y, Murphy R, Lazar HL, Shemin RJ. Endoscopic versus conventional radial artery harvest—is smaller better? J Card Surg 2006;21:329–35.
[31] Kobayashi J. Radial artery as a graft for coronary artery bypass grafting. Circ J 2009;73:1178–83.
[32] Ronan JW, Perry LA, Berner HB, Sundt 3rd TM. Radial artery harvest: comparison of ultrasonic dissection with standard technique. Ann Thorac Surg 2000;69:113–4.
[33] Reyes AT, Frame R, Brodman RF. Technique for harvesting the radial artery as a coronary artery bypass graft. Ann Thorac Surg 1995;59:118–26.
[34] Dogan OV, Duzgun C, Ozeren M, Alanoglu E, Dogan S, Simsek E, Yucel E. Subclinical injury to forearm nerves during radial harvesting: electrophysiologic study. J Card Surg 2006;21:151–4.
[35] Chen XJ, Chen X, Xie D, Meng F, Shi K, Xu M. Radial artery as conduit is safe and effective in coronary bypass surgery in the elderly single-central results from 326 patients. Circ J 2009;73:1049–54.
[36] Psacioglu H, Atay Y, Cetindag B, Saribülbül O, Buket S, Hamulu A. Easy harvesting of radial artery with ultrasonically activated scalpel. Ann Thorac Surg 1998;65:984–5.
[37] Isomura T, Suma H, Sato T, Horii T. Use of the harmonic scalpel for harvesting arterial conduits in coronary artery bypass. Eur J Cardiothorac Surg 1998;14:101–3.
[38] Wright CB, Barner CB, Gao A, Obial R, Bandy B, Perry L, Ronan J, Kelly CR. The advantages of the harmonic scalpel for the harvesting of radial arteries for coronary artery bypass. Heart Surg Forum 2001;4(3):226–30.
[39] Higami T, Kozawa S, Asada T, Shida T, Ogawa K. Skeletonization and harvest of the internal thoracic artery with an ultrasonic scalpel. Ann Thorac Surg 2000;70:307–8.
[40] Casselman FP, La Meir M, Cammu G, Wellens F, De Geest R, Degrieck I, Van Praet F, Vermeulen Y, Vanermen H. Initial experience with an endoscopic radial artery harvesting technique. J Thorac Cardiovasc Surg 2004;128:463–6.

[41] Shapira OM, Eskenazi BR, Anter E, Joseph L, Christensen TG, Hunter CT, Lazar HL, Vita JA, Shemin RJ, Keaney Jr JF. Endoscopic versus conventional radial artery harvest for coronary artery bypass grafting: functional and histologic assessment of the conduit. J Thorac Cardiovasc Surg 2006;131:388–94.
[42] Cikirikcioglu M, Yasa M, Kerry Z, Posacioglu H, Boga M, Yagdi T, Topçuoglu N, Büket S, Hamulu A. The effects of the harmonic scalpel on the vasoreactivity and endothelial integrity of the radial artery: a comparison of two different techniques. J Thorac Cardiovasc Surg 2001;122:624–6.
[43] Lamm P, Juchem G, Weyrich P, Schütz A, Reichart B. The harmonic scalpel: optimizing the quality of mammary artery bypass grafts. Ann Thorac Surg 2000;69:1833–5.
[44] Canosa C, Nasso G, De Filippo CM, Modugno P, Spatuzza P, Calvo E, Testa N, Alessandrini F. Open clip-free radial artery harvesting with the harmonic shears. J Card Surg 2007;22:139–41.
[45] Connolly MW, Torrillo LD, Stauder MJ, Patel NU, McCabe JC, Loulmet DF, Subramanian VA. Endoscopic radial artery harvesting: results of first 300 patients. Ann Thorac Surg 2002;74:502–6.
[46] Choi JB, Lee SY. Skeletonized and pedicled internal thoracic artery grafts: effect on free flow during bypass. Ann Thorac Surg 1996;61(3):909–13.
[47] Wendler O, Tscholl D, Huang Q, Schäfers HJ. Free flow capacity of skeletonized versus pedicled internal thoracic artery grafts in coronary artery bypass grafts. Eur J Cardiothorac Surg 1999;15(3):247–50.
[48] Miyagi N, Oshima N, Shirai T, Sunamori M. Skeletonised harvesting improves early-term and mid-term perfect patency of a radial artery graft. Jpn J Thorac Cardiovasc Surg 2006;54:472–6.
[49] Siminelakis S, Karfis E, Anagnostopoulos C, Toumpoulis I, Katsaraki A, Drossos G. Harvesting radial artery and neurologic complications. J Card Surg 2004;19:505–10.
[50] Abu-Omar Y, Mussa S, Anastasiadis K, Steel S, Hands L, Taggart DP. Duplex ultrasonography predicts safety of radial artery harvest in the presence of an abnormal Allen test. Ann Thorac Surg 2004;77(1):116–9.
[51] Allen EV. Thromboangiitis obliterans: methods of diagnosis of chronic occlusive arterial lesions distal to the wrist with illustrative cases. Am J Med Sci 1929;178:237.
[52] Acar C, Ramsheyi A, Pagny JY, Jebara V, Barrier P, Fabiani JN, Deloche A, Guermonprez JL, Carpentier A. The radial artery for coronary artery bypass grafting: clinical and angiographic results at five years. J Thorac Cardiovasc Surg 1998;116(6):981–9.
[53] Paletta CE, Huang DB, Fiore AC, Swartz MT, Rilloraza FL, Gardner JE. Major leg wound complications after saphenous vein harvest for coronary revascularization. Ann Thorac Surg 2000;70(2):492–7.
[54] Dietl CA, Benoit CH. Radial artery graft for coronary revascularization: technical considerations. Ann Thorac Surg 1995;60:102–10.
[55] Roberts N, Ghosh S, Boehm M, Galiñanes M. The radial hyperaemic response: a new and objective assessment of ulnar collateral supply to the hand. Eur J Cardiothorac Surg 2002;21:549–52.
[56] Agrifoglio M, Dainese L, Pasotti S, Galanti A, Cannata A, Roberto M, Parolari A, Biglioli P. Preoperative assessment of the radial artery for coronary artery bypass grafting: is the clinical Allen test adequate? Ann Thorac Surg 2005;79:570–2.
[57] Kohonen M, Teerenhovi O, Terho T, Laurikka J, Tarkka M. Is the Allen test reliable enough? Eur J Cardiothorac Surg 2007;32:902–5.
[58] Cable DG, Mullany CJ, Schaff HV. The Allen test. Ann Thorac Surg 1999;67:876–7.
[59] Fox AD, Whiteley MS, Phillips-Hughes J, Roake J. Acute upper limb ischemia: a complication of coronary artery bypass grafting. Ann Thorac Surg 1999;67:535–7.
[60] Nunoo-Mensah J. An unexpected complication after harvesting of the radial artery for coronary artery bypass grafting. Ann Thorac Surg 1998;66:929–31.
[61] Manabe S, Tabuchi N, Toyama M, Kuriu K, Mizuno T, Sunamori M. Measurement of ulnar flow is helpful in predicting ischemia after radial artery harvest. Thorac Cardiovasc Surg 2002;50:325–8.
[62] Jones BM, O'Brien CJ. Acute ischaemia of the hand resulting from elevation of a radial forearm flap. Br J Plas Surg 1985;38:396–7.
[63] Hirai M, Kawai S. False positive and negative results in Allen test. J Cardiovasc Surg 1980;21:353–60.
[64] Ruengsakulrach P, Buxton BF, Eizenberg N, Fahrer M. Anatomic assessment of hand circulation in harvesting the radial artery. J Thorac Cardiovasc Surg 2001;122:178–80.
[65] Kofidis T, Woitek F. eComment: Radial artery Doppler study in every case? Interact CardioVasc Thorac Surg 2008;7:800.
[66] Pola P, Serricchio M, Flore R, Manasse E, Favuzzi A, Possati GF. Safe removal of the radial artery for myocardial revascularization: a doppler study to prevent ischemic complications to the hand. J Thorac Cardiovasc Surg 1996;112:737–44.
[67] Kochi K, Sueda T, Orihashi K, Matsuura Y. New non-invasive test alternative to Allen's test: snuff-box technique. J Thorac Cardiovasc Surg 1999;118:756–8.
[68] Kochi K, Orihashi K, Sueda T. The snuffbox technique: reliable color Doppler method to assess hand circulation. J Thorac Cardiovasc Surg 2003;125:821–5.
[69] Hosono M, Suehiro S, Shibata T, Sasaki Y, Kumano H, Kinoshita H. Duplex scanning to assess radial artery suitability for coronary artery bypass grafting. Jpn J Thorac Cardiovasc Surg 2000;48:217–21.
[70] Ruengsakulrach P, Brooks M, Hare DL, Gordon I, Buxton BF. Preoperative assessment of hand circulation by means of Doppler ultrasonography and the modified Allen test. J Thorac Cardiovasc Surg 2001;121:526–31.
[71] Starnes SL, Wolk SW, Lampman RM, Shanley CJ, Prager RL, Kong BK, Fowler JJ, Page JM, Babcock SL, Lange LA, Erlandson EE, Whitehouse Jr WM. Noninvasive evaluation of hand circulation before radial artery harvest for coronary artery bypass grafting. J Thorac Cardiovasc Surg 1999;117:261–6.
[72] Rodriguez E, Ormont ML, Lambert EH, Needleman L, Halpern EJ, Diehl JT, Edie RN, Mannion JD. The role of preoperative radial artery ultrasound and digital plethysmography prior to coronary artery bypass grafting. Eur J Cardiothorac Surg 2001;19:135–9.
[73] Tatoulis J, Buxton B, Fuller J. The radial artery in coronary re-operations. Eur J Cardiothorac Surg 2001;19:266–73.
[74] Desai ND, Cohen EA, Naylor CD, Fremes SE. Radial Artery Patency Study Investigators. A randomized comparison of radial-artery and saphenous vein coronary by-pass grafts. N Engl J Med 2004;351:2302–9.
[75] Lemma M, Gelpi G, Mangini A, Vanelli P, Carro C, Condemi A, Antona C. Myocardial revascularization with multiple arterial grafts: comparison between the radial artery and the internal thoracic artery. Ann Thorac Surg 2001;71(6):1969–73.
[76] Trick WE, Scheckler WE, Tokars JI, Jones KC, Smith EM, Reppen ML, Jarvis WR. Risk factors for radial artery harvest site infection following coronary artery bypass graft surgery. Clin Infect Dis 2000;30:270–5.
[77] Denton TA, Trento L, Kass RM, Blanche C, Raissi S, Cheng W, Fontana GP, Trento A. Radial artery harvesting for coronary bypass operation. Neurologic complication and their potential mechanisms. J Thorac Cardiovasc Surg 2001;121:951–6.
[78] Sajja LR, Mannam G, Sompalli S. Neurologic hand complications after radial artery harvest for coronary artery by-pass grafting. J Thorac Cardiovasc Surg 2002;123(3):585–6.
[79] Shapira OM, Xu A, Aldea GS, Vita JA, Shemin RJ, Keaney Jr JF. Nitroglycerin is superior to diltiazem as a coronary bypass conduit vasodilator. J Thorac Cardiovasc Surg 1999;117:906–11.
[80] Kaufer E, Factor SM, Frame R, Brodman RF. Pathology of the radial and internal thoracic arteries used as coronary artery bypass grafts. Ann Thorac Surg 1997;63:1118–22.
[81] Nicolosi AC, Pohl LL, Parsons P, Cambria RA, Olinger GN. Increased incidence of radial artery calcification in patients with diabetes mellitus. J Surg Res 2002;102:1–5.
[82] Deshpande RP, Chukwuemeka A, Iqbal A, Desai JB. Dystrophic calcification of the radial artery. Ann Thorac Surg 2000;69:1939–40.
[83] Gaudino M, Tondi P, Serricchio M, Spatuzza P, Santoliquido A, Flora R, Girola F, Nasso G, Pola P, Possati G. Atherosclerotic involvement of the radial artery in patients with coronary artery disease and its relation with midterm radial artery graft patency and endothelial function. J Thorac Cardiovasc Surg 2003;126:1968–71.
[84] Ikeda M, Ohashi H, Tsutsumi Y, Hige K, Kawai T, Ohnaka M. Angiographic evaluation of the luminal changes in the radial artery graft in coronary artery bypass surgery: a concern over the long-term patency. Eur J Cardiothorac Surg 2002;21:800–3.
[85] Hagiwara H, Ito T, Kamiya H, Akita T, Usui A, Ueda Y. Mid-term structural change in the radial artery grafts after coronary artery bypass grafting. Ann Thorac Surg 2004;77:805–11.
[86] Possati G, Gaudino M, Prati F, Alessandrini F, Trani C, Glieca F, Mazzari MA, Luciani N, Schiavoni G. Long-term results of the radial artery used for myocardial revascularization. Circulation 2003;108:1350–4.
[87] He GW, Liu ZG. Comparison of nitric oxide release and endothelium-derived hyperpolarizing factor-mediated hyperpolarization between human radial and internal mammary arteries. Circulation 2001;104(Suppl. I):I344–9.
[88] Acar C, Jebara VA, Portoghese M, Fontaliran F, Dervanian P, Chachques JC, Meininger V, Carpentier A. Comparative anatomy and histology of the radial artery and the internal thoracic artery. Implication for coronary artery bypass. Surg Radiol Anat 1991;13:283–8.
[89] Van Son JA, Smedts F, Vincent JG, van Lier HJ, Kubat K. Comparative anatomic studies of various arterial conduits for myocardial revascularization. J Thorac Cardiovasc Surg 1990;99:703–7.
[90] He GW. Arterial grafts for coronary artery bypass grafting: biological characteristics, functional classification, and clinical choice [Review]. Ann Thorac Surg 1999;67:277–84.
[91] He GW, Yang CQ. Radial artery has higher receptor-mediated contractility but similar endothelial function compared with mammary artery. Ann Thorac Surg 1997;63:1346–52.
[92] He GW, Yang CQ. Characteristics of adrenoceptors in the human radial artery: clinical implications. J Thorac Cardiovasc Surg 1998;115:1136–41.
[93] Liu JJ, Chen JR, Buxton BF. Unique response of human arteries to endothelin B receptor agonist and antagonist. Clin Sci 1996;90:91–6.
[94] Chester AH, Amrani M, Borland JA. Vascular biology of the radial artery. Curr Opin Cardiol 1998;13:447–52.
[95] Maniar HS, Sundt TM, Barner HB, Prasad SM, Peterson L, Absi T, Moustakidis P. Effect of target stenosis and location on radial artery graft patency. J Thorac Cardiovasc Surg 2002;123:45–52.
[96] Royse AG, Royse CF, Tatoulis J, Grigg LE, Shah P, Hunt D, Better N, Marasco SF. Postoperative radial artery angiography for coronary bypass surgery. Eur J Cardiothorac Surg 2000;17:294–304.

[97] Nakajima H, Kobayashi J, Tagusari O, Bando K, Niwaya K, Kitamura S. Competitive flow in arterial composite grafts and effect of graft arrangement in off-pump coronary revascularization. Ann Thorac Surg 2004;78:481–6.
[98] Lemma M, Mangini A, Gelpi G, Innorta A, Spina A, Antona C. Is it better to use radial artery as a composite graft? Clinical and angiographic results of aorta-coronary versus Y-graft. Eur J Cardiothorac Surg 2004;26:110–7.
[99] Yie K, Na C, Oh SS, Kim J, Shinn S, Seo H. Angiographic results of the radial artery graft patency according to the degree of native coronary stenosis. Eur J Cardiothorac Surg 2008;33:341–8.
[100] Maniar HS, Barner HB, Bailey MS, Prasad SM, Moon MR, Pasque MK, Lester ML, Gay WA, Damiano RJ. Radial artery patency: are aortocoronary conduits superior to composite grafting? Ann Thorac Surg 2003;76:1498–504.
[101] Gaudino M, Alessandrini F, Pragliola C, Cellini C, Glieca F, Luciani N, Girola F, Possati G. Effect of target artery location and severity of stenosis on midterm patency of aorta-anastomosed vs internal artery-anastomosed radial artery grafts. Eur J Cardiothorac Surg 2004;25:424–8.
[102] Nakajima H, Kobayashi J, Tagusari O, Niwaya K, Funatsu T, Kawamura A, Yagihara T, Kitamura S. Angiographic flow grading and graft arrangement of arterial conduits. J Thorac Cardiovasc Surg 2006;132:1023–9.
[103] Nakajima H, Kobayashi J, Tagusari O, Bando K, Niwaya K, Kitamura S. Functional angiographic evaluation of individual, sequential, and composite arterial grafts. Ann Thorac Surg 2006;81:807–14.
[104] Iacò AL, Teodori G, Di Giammarco G, Di Mauro M, Storto L, Mazzei V, Vitolla G, Mostafa B, Calafiore AM. Radial artery for myocardial revascularization: long-term clinical and angiographic results. Ann Thorac Surg 2001;72:464–8.
[105] Tatoulis J, Buxton BF, Fuller JA. Bilateral radial artery grafts in coronary reconstruction: technique and early results in 261 patients. Ann Thorac Surg 1998;66(3):714–20.
[106] Chen AH, Nakao T, Brodman RF, Greenberg M, Charney R, Menegus M, Johnson M, Grose R, Frame R, Hu EC, Choi HK, Safyer S. Early postoperative angiographic assessment of radial grafts used for coronary artery bypass grafting. J Thorac Cardiovasc Surg 1996;111(6):1208–12.
[107] Possati G, Gaudino M, Alessandrini F, Luciani N, Glieca F, Trani C, Cellini C, Canosa C, Di Sciascio G. Mid-term clinical and angiographic results of radial artery grafts used for myocardial revascularization. J Thorac Cardiovasc Surg 1998;116:1015–21.
[108] Bhan A, Gupta V, Choudhary SK, Sharma R, Singh B, Arrawal R, Bhargava B, Sharma AV, Venugopal P. Radial artery in CABG: could the early results be comparable to internal mammary artery graft? Ann Thorac Surg 1999;67:1631–6.
[109] Buxton BF, Fuller JA, Tatoulis J. Evolution of complete arterial grafting for coronary artery disease. Tex Heart Inst J 1998;25:17–23.
[110] Manabe S, Sunamori M. Radial artery graft for coronary artery bypass surgery: biological characteristics and clinical outcome. J Card Surg 2006;21:102–14.
[111] Wildhirt SM, Voss B, von Canal F, Benz M, Grammer JB, Bauernschmitt R, Tassani P, Lange R. Graft function, histopathology and morphometry of radial arteries used as conduits for myocardial revascularization in patients beyond 70. Eur J Cardiothorac Surg 2006;30:333–40.
[112] Onorati F, Pezzo F, Comi MC, Impiombato B, Esposito A, Polistina M, Renzulli A. Radial artery graft function is not affected by age. J Thorac Cardiovasc Surg 2007;134(5):1112–20.
[113] Modine T, Al-Ruzzeh S, Mazrani W, Azeem F, Bustami M, Ilsley C, Amrani M. Use of radial artery graft reduces the morbidity of coronary artery bypass graft surgery in patients aged 65 years and older. Ann Thorac Surg 2002;74(4):1144–7.
[114] Mussa S, Choudhary BP, Taggart DP. Radial artery conduits for coronary artery bypass grafting: current perspective. J Thorac Cardiovasc Surg 2005;129:250–3.
[115] Yoshizaki T, Tabuchi N, Toyama M. Verapamil and nitroglycerin improves the patency rate of radial artery grafts. Asian Cardiovasc Thorac Ann 2008;16:396–400.
[116] Verma S, Szmitko PE, Weisel RD, Bonneau D, Latter D, Errett L, LeClerc Y, Fremes SE. Should radial arteries be used routinely for coronary artery bypass grafting? Circulation 2004;110:e40–6.
[117] Maruo A, Hamner CE, Rodrigues AJ, Higami T, Greenleaf JF, Schaff HV. Nitric oxide and prostacyclin in ultrasonic vasodilatation of the canine internal mammary artery. Ann Thorac 2004;77:126–32.
[118] Myers MG, Fremes SE. Prevention of radial artery graft spasm: a survey of Canadian surgical centres. Can J Cardiol 2003;19:677–81.
[119] Tatoulis J, Jiang GC, Moffat JD, Cocks TM. Storage of radial artery grafts in blood increases vessel reactivity in vasoconstrictors in vitro. Ann Thorac Surg 1999;68:2191–5.
[120] He GW, Yang CQ. Use of verapamil and nitroglycerin solution in preparation of radial artery for coronary grafting. Ann Thorac Surg 1996;61:610–4.
[121] Borger MA, Cohen G, Buth KJ, Rao V, Bozinovski J, Liaghati-Nasseri N, Borger MA, Cohen G, Buth KJ, Rao V, Bozinovski J, Liaghati-Nasseri N. Multiple arterial grafts. Radial versus right internal thoracic arteries. Circulation 1998;98(Suppl. II):7–14.
[122] Dipp MA, Nye PC, Taggart DP. Phenoxybenzamine is more effective and less harmful than papaverine in the prevention of radial artery vasospasm. Eur J Cardiothorac Surg 2001;19:482–6.
[123] Corvera JS, Morris CD, Budde JM, Velez DA, Puskas JD, Lattouf OM, Cooper WA, Guyton RA, Vinten-Johansen J. Pretreatment with phenoxybenzamine attenuates the radial artery's vasoconstrictor response to alpha-adrenergic stimuli. J Thorac Cardiovasc Surg 2003;126:1549–54.
[124] He GW, Yang CQ. Vasorelaxant effect of phosphodiesterase-inhibitor milrinone in the human radial artery used as coronary bypass graft. J Thorac Cardiovasc Surg 2000;119:1039–45.
[125] Cable DG, Caccitilo JA, Pearson PJ, O'Brien T, Mullany CJ, Daly RC, Orszulak TA, Schaff HB. Approaches to prevention and treatment of radial artery graft vasospasms. Circulation 1998;98:15–22.
[126] Mussa S, Guzik TJ, Black E, Dipp MA, Channon KM, Taggart DP. Comparative efficacies and durations of action of phenoxybenzamine, verapamil/nitroglycerin solution, and papaverine as topical antispasmodics for radial artery coronary bypass grafting. J Thorac Cardiovasc Surg 2003;126:1798–805.
[127] Mussa S, Prior T, Alp N, Wood K, Channon KM, Taggart DP. Duration of action of antispasmodic agents: novel use of a mouse model as an in vivo pharmacological assay. Eur J Cardiothorac Surg 2004;26:988–94.
[128] Kulik A, Rubens FD, Gunning D, Bourke ME, Mesana TG, Ruel M. Radial artery graft treatment with phenoxybenzamine is clinically safe and may reduce perioperative myocardial injury. Ann Thorac Surg 2007;83:502–9.
[129] He GW, Yang CQ. Pharmacological studies and guidelines for the use of vasodilators for arterial grafts. In: He GW, editor. Arterial grafts for coronary artery bypass surgery. Singapore: Springer; 1999. p. 69–79.
[130] He GW. Verapamil plus nitroglycerin solution maximally preserves endothelial function of the radial artery: comparison with papaverine solution. J Thorac Cardiovasc Surg 1998;115:1321–7.
[131] Rubens FD, Labow RS, Meek E, Bedard E, Gill IS, Dudani AK, Ganz PR. Papaverine solutions cause loss of viability of endothelial cells. J Cardiovasc Surg (Torino) 1998;39:193–9.
[132] Gao YJ, Stead S, Lee RM. Papaverine induces apoptosis in vascular endothelial and smooth muscle cells. Life Sci 2002;70:2675–85.
[133] Orime Y, Shiono M, Hata H, Yagi S, Tsukamoto S, Okumura H, Kimura S, Hata M, Sezai A, Obana M, Sezai Y. Effects of phosphodiesterase inhibitors after coronary artery bypass grafting. Jpn Circ J 1999;63:117–22.
[134] Velez DA, Morris CD, Muraki S, Budde JM, Otto RN, Zhao ZQ, Guyton RA, Vinten-Johansen J. Brief pretreatment of radial artery conduits with phenoxybenzamine prevents vasoconstriction long term. Ann Thorac Surg 2001;72:1977–84.
[135] Conant AR, Shackcloth MJ, Oo AY, Chester MR, Simpson AW, Dihmis WC. Phenoxybenzamine treatment is insufficient to prevent spasm in the radial artery: the effect of other vasodilators. J Thorac Cardiovasc Surg 2003;126:448–54.
[136] Royse AG, Royse CF, Shah P, Williams A, Kaushik S, Tatoulis J. Radial artery harvest technique, use and functional outcome. Eur J Cardiothorac Surg 1999;15:186–93.
[137] Meharwal ZS, Trehan N. Functional status of the hand after radial artery harvesting: results in 3,977 cases. Ann Thorac Surg 2001;72:1557–61.
[138] Saeed I, Anyuanwu AC, Yacoub MH, Amrani M. Subjective patient outcomes following coronary artery bypass using the radial artery: results of the harvest site complications and quality of life. Eur J Cardiothorac Surg 2001;20:1141–6.
[139] Greene MA, Malias MA. Arm complications after radial artery procurement for coronary bypass operation. Ann Thorac Surg 2001;72(1):126–8.
[140] Budillon AM, Nicolini F, Agostinelli A, Beghi C, Pavesi G, Fragnito C, Busi M, Gherli T. Complications after radial artery harvesting for coronary artery bypass grafting: our experience. Surgery 2003;133:283–7.
[141] Chong WC, Ong PJ, Hayward CS, Collins P, Moat NE. Effects of radial artery harvesting on forearm function and blood flow. Ann Thorac Surg 2003;75:1171–4.
[142] Brodman RF, Hirsh LE, Frame R. Effect of radial artery harvest on collateral forearm blood flow and digital perfusion. J Thorac Cardiovasc Surg 2002;123:512–6.
[143] Manabe S, Tabuchi N, Toyama M, Yoshizaki T, Kato M, Wu H, Kotani M, Sunamori M. Oxygen pressure measurement during grip exercise reveals exercise intolerance after radial harvest. Ann Thorac Surg 2004;77:2066–70.
[144] Royse AG, Royse CF, Maleskar A, Garg A. Harvest of the radial artery for coronary artery surgery preserves maximal blood flow of the forearm. Ann Thorac Surg 2004;78:539–42.
[145] Anyanwu AC, Saeed I, Bustami M, Ilsley C, Yacoub MH, Amrani M. Does routine use of the radial artery increase the complexity or morbidity of coronary by pass surgery? Ann Thorac Surg 2001;71(2):555–9.
[146] Hata M, Raman J, Seevanayagam S, Hare D, Buxton BF. Post radial artery harvest hand perception: postoperative 12-month follow-up results. Circ J 2002;66:816–8.
[147] Galajda Z, Szentkiralyi I, Peterffy A. Neurologic complications after radial artery harvesting. J Thorac Cardiovasc Surg 2002;123(1):194–5.
[148] DeGowin RL, Brown DD. DeGowin's diagnostic examination. Neurologic examination. 7th ed. New Baskerville, USA: McGraw-Hill; 2000. p. 759–822.
[149] Brodman RF, Frame R, Camacho M, Hu E, Chen A, Hollinger I. Routine use of unilateral and bilateral radial arteries for coronary artery bypass graft surgery. J Am Coll Cardiol 1996;28:959–63.
[150] Shapira OM, Alkon JD, Aldea GS, Madera F, Lazar HL, Shemin RJ. Clinical outcomes in patients undergoing coronary artery bypass grafting with preferred use of the radial artery. J Card Surg 1997;12:381–8.
[151] Sudhakar CB, Forman DL, Dewar ML, Shaw RK, Fusi S. Free radial artery grafts: surgical technique and results. Ann Plast Surg 1999;67:876–7.

[152] Genovesi MH, Torrillo L, Fonger J, Patel N, McCabe JC, Subramanian VA. Endoscopic radial artery harvest: a new approach. Heart Surg Forum 2001;4:223–4.
[153] Cohen G, Tamariz MG, Sever JY, Liaghati N, Guru V, Christakis GT, Bhatnagar G, Cutrara C, Abouzahr L, Goldman BS, Fremes SE. The radial artery versus the saphenous vein graft in contemporary CABG: a case-matched study. Ann Thorac Surg 2001;71(1):180–6.
[154] Zacharias A, Habib RH, Schwann TA, Riordan CJ, Durham SJ, Shah A. Improved survival with radial artery versus vein conduits in coronary bypass surgery with left internal thoracic artery to left anterior descending artery grafting. Circulation 2004;109:1489–96.
[155] Santarpino G, Onorati F, Cristodoro L, Scalas C, Mastroroberto P, Renzulli A. Radial artery graft flowmetry is better than saphenous vein on postero-lateral wall. Int J Cardiol 2010;143(2):158–64.
[156] Calafiore AM, Di Giammarco G, Teodori G, D'Annunzio E, Vitolla G, Fino C, Maddestra N. Radial artery and inferior epigastric artery in composite grafts: improved midterm angiographic results. Ann Thorac Surg 1995;60(3):517–24.
[157] Amano A, Hirose H, Takahashi A, Nagano N. Coronary artery bypass grafting using the radial artery: mid-term results in a Japanese institute. Ann Thorac Surg 2001;72:120–5.
[158] da Costa FD, da Costa IA, Poffo R, Abuchaim D, Gaspar R, Garcia L, Faraco DL. Myocardial revascularization with the radial artery: a clinical and angiographic study. Ann Thorac Surg 1996;62:475–80.
[159] Cameron J, Trivedi S, Stafford G, Bett JH. Five-year angiographic patency of radial artery bypass grafts. Circulation 2004;110(Suppl. II):II-23–6.
[160] Khot UN, Friedman DT, Pettersson G, Smedira NG, Li J, Ellis SG. Radial artery bypass grafts have an increased occurrence of angiographically severe stenosis and occlusion compared with left internal mammary arteries and saphenous vein grafts. Circulation 2004;109:2086–91.
[161] Lιgarι JF, Buth KJ, Sullivan JA, Hirsch GM. Composite arterial grafts versus conventional grafting for coronary artery bypass grafting. J Thorac Cardiovasc Surg 2004;127:160–6.
[162] Shah PJ, Durairaj M, Gordon I, Fuller J, Rosalion A, Seevanayagam S, Tatoulis J, Buxton BF. Factors affecting patency of internal thoracic artery graft: clinical and angiographic study in 1434 symptomatic patients operated between 1982 and 2002. Eur J Cardiothorac Surg 2004;26:118–24.
[163] Shah PJ, Bui K, Blackmore S, Gordon I, Hare DL, Fuller J, Seevanayagam S, Buxton BF. Has the in situ right internal thoracic artery been overlooked? An angiographic study of the radial artery, internal thoracic arteries and saphenous vein graft patencies in symptomatic patients. Eur J Cardiothorac Surg 2005;27:870–5.
[164] Erdil N, Nisanoglu V, Eroglu T, Fansa I, Cihan HB, Battaloglu B. Early outcomes of radial artery use in all-arterial grafting of the coronary arteries in patients 65 years and older. Tex Heart Inst J 2010;37(3):301–6.
[165] Tatoulis J, Buxton BF, Fuller JA, Royse AG. Total arterial coronary revascularization: techniques and results in 3,220 patients. Ann Thorac Surg 1999;68(6):2093–9.
[166] DeLaria GA, Hunter JA, Goldin MD, Serry C, Javid H, Najafi H. Leg wound complications associated with coronary revascularization. J Thorac Cardiovasc Surg 1981;81(3):403–7.
[167] Utley JR, Thomason ME, Wallace DJ, Mutch DW, Staton L, Brown V, Wilde CM, Bell MS. Preoperative correlates of impaired wound healing after saphenous vein excision. J Thorac Cardiovasc Surg 1989;98(1):147–9.
[168] Slaughter MS, Olson MM, Lee Jr JT, Ward HB. A fifteen-year wound surveillance study after coronary artery bypass. Ann Thorac Surg 1993;56(5):1063–8.
[169] Calafiore AM, Di Mauro M, D'Alessandro S, Teodori G, Vitolla G, Contini M, Iacò AL, Spira G. Revascularization of the lateral wall: long-term angiographic and clinical results of radial artery versus right internal thoracic artery grafting. J Thorac Cardiovasc Surg 2002;123:225–31.
[170] Buxton BF, Raman JS, Ruengsakulrach. Radial artery patency and clinical outcomes: five-year interim results of a randomized trial. J Thorac Cardiovasc Surg 2003;125:1363–71.
[171] Endo M, Nishida H, Tomizawa Y, Kasanuki H. Benefit of bilateral over single internal mammary artery grafts for multiple coronary artery bypass grafting. Circulation 2001;104:2164–70.
[172] Berreklouw E, Rademakers PP, Koster JM, van Leur L, van der Wielen BJ, Westers P. Better ischemic event-free survival after two internal thoracic artery grafts: 13 years of follow-up. Ann Thorac Surg 2001;72:1535–41.
[173] Stevens LM, Carrier M, Perrault LP, Hιbert Y, Cartier R, Bouchard D, Fortier A, El-Hamamsy I, Pellerin M. Single versus bilateral internal thoracic artery grafts with concomitant saphenous vein grafts for multivessel coronary artery bypass grafting: effects on mortality and event-free survival. J Thorac Cardiovasc Surg 2004;127:1408–15.
[174] Grossi EA, Esposito R, Harris LJ, Crooke GA, Galloway AC, Colvin SB, Culliford AT, Baumann FG, Yao K, Spencer FC. Sternal wound infections and use of internal mammary artery grafts. J Thorac Cardiovasc Surg 1991;102:342–7.
[175] Matsa M, Paz Y, Gurevich J, Shapira I, Kramer A, Pevny D, Mohr R. Bilateral skeletonized internal thoracic artery grafts in patients with diabetes mellitus. J Thorac Cardiovasc Surg 2001;121:668–74.
[176] Choudhary BP, Antoniades C, Brading AF, Galione A, Channon K, Taggart DP. Diabetes mellitus as a predictor for radial artery vasoreactivity in patients undergoing coronary artery bypass grafting. J Am Coll Cardiol 2007;50:1047–53.
[177] Roques F, Nashef SA, Michel P, Gauducheau E, de Vincentiis C, Baudet E, Cortina J, David M, Faichney A, Gabrielle F, Gams E, Harjula A, Jones MT, Pintor PP, Salamon R, et al. Risk factors and outcome in European cardiac surgery: analysis of the EuroSCORE multinational database of 19030 patients. Eur J Cardiothorac Surg 1999;15(6):816–22 [discussion 822-823].
[178] Wendler O, Landwehr P, Bandner-Risch D, Georg T, Schäfers HJ. Vasoreactivity of arterial grafts in the patient with diabetes mellitus: investigations on internal thoracic artery and radial artery conduits. Eur J Cardiothorac Surg 2001;20:305–11.
[179] Baikoussis NG. Radial artery as graft for myocardial revascularization. Ann Thorac Surg 2013;96(September (3)):1122.